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Electric drive control system of the paper-making machine

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Electric drive control system of the paper-making machine

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Abstract. Here are presented the synthesis of paper-making machine electric drives control systems. Quality indicators of paper and cardboard are directly related to the accuracy characteristics of the electric drives of both machine wires in conditions of unpredictable changes in loads on their shafts. It is shown that to solve the problem of stabilization of wires velocities and their ratio it is advisable to implement the principle of servo control. It is proposed to use the lower wire speed stabilization subsystem as the leading one, and the upper wire speed servo subsystem with the stabilization of the zero deviation of the integral from difference of electric drives speed. Presents the results of a synthesis and analysis of two-dimensional servo system finite electric drives control in conception of the modern vector-matrix control theory. A discrete-continuous mathematical model of the electromechanical system is obtained. To ensure the quality of speed control, discrete finite state regulators are used. As a result of the synthesis, expressions for the implementation of a discrete control device are obtained. In simulation, the reactions of the drives to the increment of the speed and to the increments of the loads on the drive shafts are obtained. The simulation results showed the effectiveness of the proposed principles of electric drive control. The electromechanical system demonstrates the properties of astatic control and reduces the deviation of velocities in steady-state modes to zero. The solution to the problem of reducing the mutual influence of electric actuators for the stabilization of the velocities of the machine wire and maintaining them in the specified ratios will reduce to a minimum the displacement of the paper layers formed on both machine wires. The practical application of the proposed electric drive control system in production contributes to improving the quality of products manufactured on a paper machine.

1. Introduction and problem statement

Twin-fourdrinier paper and cardboard making machines (PMM) belong to one of the last generations and are most in demand by consumers of paper and cardboard due to the possibility of implementing various consumer qualities of the products [1, 2]. At the same time, algorithms of control of machine wire drives and adjustment of electromechanical control system (EMCS) of the fourdrinier section have a significant influence on physical and mechanical properties and characteristics of paper web. EMCS allows ensuring minimum variation of wire speed deviations and stabilization of paper web quality indicators [1, 3].

The tension and driving of the lower machine wire is carried out by means of a number of rolls – couch roll, turning roll, sub-wire roller and breast roll, and the upper wire by means of wire-leading and combined rolls [2, 3].

The initial tension of the paper web is formed in the fourdrinier section of the PMM, which provides controlled wiring of the paper web, and without it, the movement of the paper web becomes uncontrollable. The problem of forming the required tension [4] of the paper web on the machine wires is that it is not yet fully formed. This leads to the fact that it is very problematic to control the tension of a wet paper web using tension sensors, since the dryness of the paper web even at the end of the fourdrinier section is only 15-23% [1, 2]. At the same time, already in the fourdrinier section, the tension of the paper web directly affects the orientation of the fibers in the longitudinal and cross-section and, as a consequence, the mechanical, elastoplastic, hydrophobic and other properties of paper and cardboard.

Currently, the function of indirect control of web tension is realized on the basis of control of currents (electromagnetic moments) of electric motors, which indirectly determine the change of loads on the shafts of electric motors, leading to changes in the linear velocities of machine wires and, accordingly, the tension of the paper web [2-4]. In some cases, indirect control of the tension of wet paper web is implemented on the basis of monitoring the relative change in the width and speed of the paper web, but this approach can be applied only to the drives of the press section.

Information about the currents in the windings and speeds of electric motors is used to solve two interrelated problems:

- regulation of the tension of the paper web on each of the wires due to the distribution of loads between the drives;
- changing the ratio of linear velocities of two wires in steady-state modes due to manual or automated action on one of the drives.

DC motors are used to drive PMM wires, but in the formulation of the research problem, the type of drive is not significant.

The mutual influence of machine wires control subsystems makes it necessary to solve the complex problem of multi-connected control of electric drives to achieve the quality of produced paper (cardboard). At the same time, the quality of the double-sided paper web significantly depends on the mismatch of the instantaneous speeds of the leading electric drives of the two machine wires. The problem of optimization of two-dimensional control of electric drives is not solved at the present time.

Therefore, it is proposed to consider the problem of stabilization of the ratio of linear velocities of machine wire as a priority task. This allows us to apply the principle of tracking control [5] to the drive of one of the wires, considering it as a slave, whose speed is adjusted to the change in the speed of the drive. In this case, the load on the shafts of the auxiliary drives of both wires, affecting the tension of the paper web, it is advisable to consider as disturbing effects that act on the leading drives of the machine wires. Load changes have the greatest impact on the speed of the electric drive of the lower wire. Therefore, on the basis of the lower wire drive, it is advisable to implement the function of stabilizing the speed of the lower wire and use it as a leading subsystem. And on the basis of the upper wire drive to realize the function of regulating the mismatch of the speeds of the lower and upper wires (in addition to the speed stabilization function), thus using it as a servo drive of the fourdrinier section.

2. Main part

The synthesis of the machine wire electric drive control system is usually carried out on the principle of cascade control [3], when each of the EMCS circuits includes the same structure of the motor speed control system with subordinate control circuits of electromagnetic moments (armature currents). Consider the synthesis of electric drive control system of the fourdrinier section, with the following main parameters: wires width 2.6 m, length of the lower wire − 32 meters, length of upper wire −15.2 meters, length of the lower forming table – 13.75 m, the upper – 5.75 m, maximum linear paper web speed − 10 m/s. The electric drive of the machine wire is made on the basis of four identical DC motors with individual Siemens Simoreg DC thyristor converters. The values of the main nominal parameters of motors: power - 105 kW, armature voltage - 440 V, rotation speed-183 rad/s, armature current - 263 A.

Machine wire speeds are regulated by changing the anchor voltage of the motors with a constant excitation flow. Two motors can be considered as the main ones for moving the paper web. Thus, in the synthesis of the fourdrinier section EMCS, only two electric drives can be considered – the couch roll of the lower wire and the wire-leading roll of the upper wire.

A simplified functional and structural diagram of a two-dimensional EMCS with cascade control is shown in figure 1.

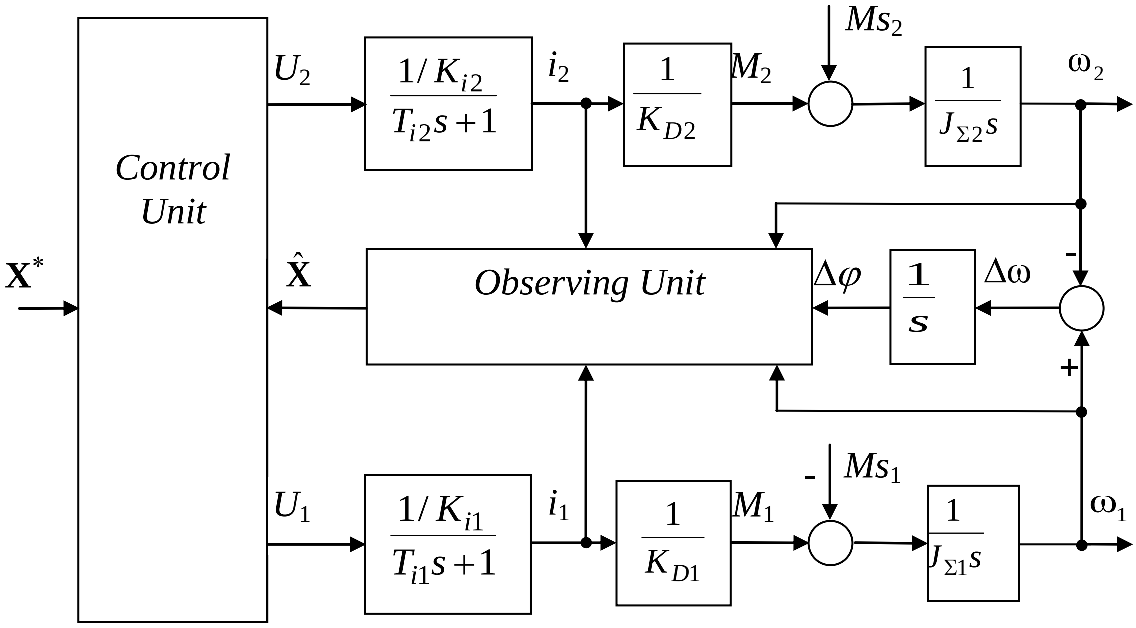

Figure 1. Functional-structural scheme of EMCS.

In figure 1 the following notation: the index 1 corresponds to the parameters and variables leading subsystems of couch roll drive; index 2 – the slave servo subsystem of wire-leading drive of the upper wire; Control Unit − generates an interlocking control of the leading wire drives; Observing Unit − generates signals to be measured and observed variables; K_{i1}, K_{i2} – transmission coefficients of armature currents feedbacks, T_{i1}, T_{i2} – closed control loops time constant of armature currents; K_{D1}, K_{D2} – transmission coefficients of electric motors, $J_{\Sigma 1}$, $J_{\Sigma 2}$ – equivalent moments of inertia; **X*** – vector of EMCS setting effects; $\hat{\mathbf{X}}$ – vector of measured or observed variables; U_1, U_2 – discrete control actions; i_1, i_2 – armature currents of motors; M_1, M_2 – motors torque; M_{S1}, M_{S2} – load torque on the motors shafts; ω_1, ω_2 – rotation speed of the motor shafts; $\Delta\omega$, $\Delta\varphi$ – respectively, the mismatch of motors speeds and its integral; s – Laplace operator.

As a result of simple calculations [3, 6] the parameters of the block diagram were obtained: K_{i1} = K_{i2} = 0,0152 Ohm; $T_{i1} = T_{i2}$ = 0.02 s; $K_{D1} = K_{D2}$ = 0.434 $(V\cdot s)^{-1}$; $J_{\Sigma 1}$ = 33,7 $kg\cdot m^2$; $J_{\Sigma 2}$ = 23 $kg\cdot m^2$.

In mathematical description of the EMCS, as it follows from figure 1, a number of assumptions: the mechanical part of the machine wire drives linearized single mass subsystems, closed loop armature current regulation approximated by an first order aperiodic link, the sensor state variables and devices of transmission and transformation of information represented by instantaneous element. Since there are no load sensors on the drive shafts, it is possible to use the observing devices [7, 8] included in the Observing Unit for their evaluation.

Discrete-continuous mathematical model, taking into account the assumptions, can be written in vector-matrix form [6-11]:

$$\dot{\mathbf{X}}(t) = \mathbf{AX}(t) + \mathbf{BU}(kT) + \mathbf{CF}(t), \qquad (1)$$

where $\mathbf{X}(t)$ is the vector of model variables, $X(t)=[\omega_1, i_1, \Delta\varphi, \omega_2, i_2]^T$, ^{T} – transpose symbol; $\mathbf{U}(kT)$ – discrete control vector EMCS, $\mathbf{U}(kT)=[U_1(kT), U_2(kT)]^T$, T – control period; $\mathbf{F}(t)$ – vector of load torque on the motors, $\mathbf{F}(t)=[M_{S1}, M_{S2}]^T$; **A**, **B**, **C** – respectively, matrix state, control and perturbation:

$$\mathbf{A} = \begin{bmatrix} 0 & 1/J_{\Sigma 1}K_{D1} & 0 & 0 & 0 \\ 0 & -1/T_{i1} & 0 & 0 & 0 \\ 1 & 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 0 & 1/J_{\Sigma 2}K_{D2} \\ 0 & 0 & 0 & 0 & -1/T_{i2} \end{bmatrix};$$

$$\mathbf{B} = \begin{bmatrix} 0 & 0 \\ 1/T_{i1}K_{i1} & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 1/T_{i2}K_{i2} \end{bmatrix}; \quad \mathbf{C} = \begin{bmatrix} -1/J_{\Sigma 1} & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & -1/J_{\Sigma 2} \\ 0 & 0 \end{bmatrix}.$$

Discrete finite state regulators are used to regulate of wires velocities, which provide increased control quality indicators (speed and accuracy) in comparison with typical polynomial PI - and PID-speed regulators [6, 10]. In addition, the subsystem of stabilization of the speed of the upper wire includes additional feedback on the integral of the motors speed difference. This allows you to organize a mode of tracking the speed of the upper wire for changes in the speed of the lower wire, and thereby stabilize the relative displacement of the upper and lower layers of paper at the zero level, i.e. to provide $\Delta\varphi \cong 0$.

In accordance with the method of synthesis of finite regulators of arbitrary order [10], for the above parameters of EMCS and period T of discrete control equal to 0.02 s, the following expressions for discrete controls are obtained:

$$U_1(kT) = 17,61(\omega_1^*(kT) - \omega_1(kT)) - 0,0189 i_1(kT) + 0,01483\widehat{M}_{S1}(kT), \tag{2}$$

$$U_2(kT) = 601,4(-\Delta\varphi^*(kT) + \Delta\varphi(kT)) + 23,07(\omega_2^*(kT) - \omega_2(kT)) - 0,0251\, i_2(kT) + 0,0175\widehat{M}_{S2}(kT). \tag{3}$$

As follows from (2), (3) as a vector of the setting influences the vector is considered:

$$\mathbf{X}^*(kT) = [\Delta\varphi^*(kT),\ \omega_1^*(kT),\ \omega_2^*(kT)]^{\mathrm{T}}, \tag{4}$$

where $\omega_1^*(kT),\ \omega_2^*(kT)$ – set the speed of the actuator, respectively, the lower and upper wire drives, assumed to be the same to ensure the same linear velocity wires; $\Delta\varphi^*(kT)$ – a parameter proportional to the relative elongation of the paper web, which should be zero for equal speeds of formation of the lower and upper layers. For smooth transfer of PMM from one speed to another and limitation of motor currents these setting influences form with the second kind intensity set-point device (S-ramps) [3, 6].

The results of simulation of drive reactions to the same increment of speed setting "in small", equal to 0.1 rad/s, are shown in figure 2.

The response of the drives to the stepped increments of load torque of the master and slave drives, simulated respectively at time t = 0 c and t = 0.15 c, are shown in figure 3.

The increments of load torques are taken to be 500 Nm and 200 Nm respectively, which corresponds to the realization of the power of the order of 40-100 % of the nominal value. In these figures, the master drive variables correspond to the footnotes to position 1, the slave drive variables to position 2.

Simulation of random character of change load torques from various dehydrating devices a paper cloth is realized by imposing of additive hindrance in the form of "white noise" with the parameters corresponding to the actual data of research of the fourdrinier section drives [2, 3].

As can be seen from the figure 3, transients in EMCS are completed in 2-5 periods of discrete control and depend on the place of application of additive setting and disturbing influences. This indicates the effectiveness of the implementation of the finite control of electric drives, both in autonomous mode (for each of the wires separately) and in the tracking mode when the driven subsystem follows to the integral of the machine wires speed difference.

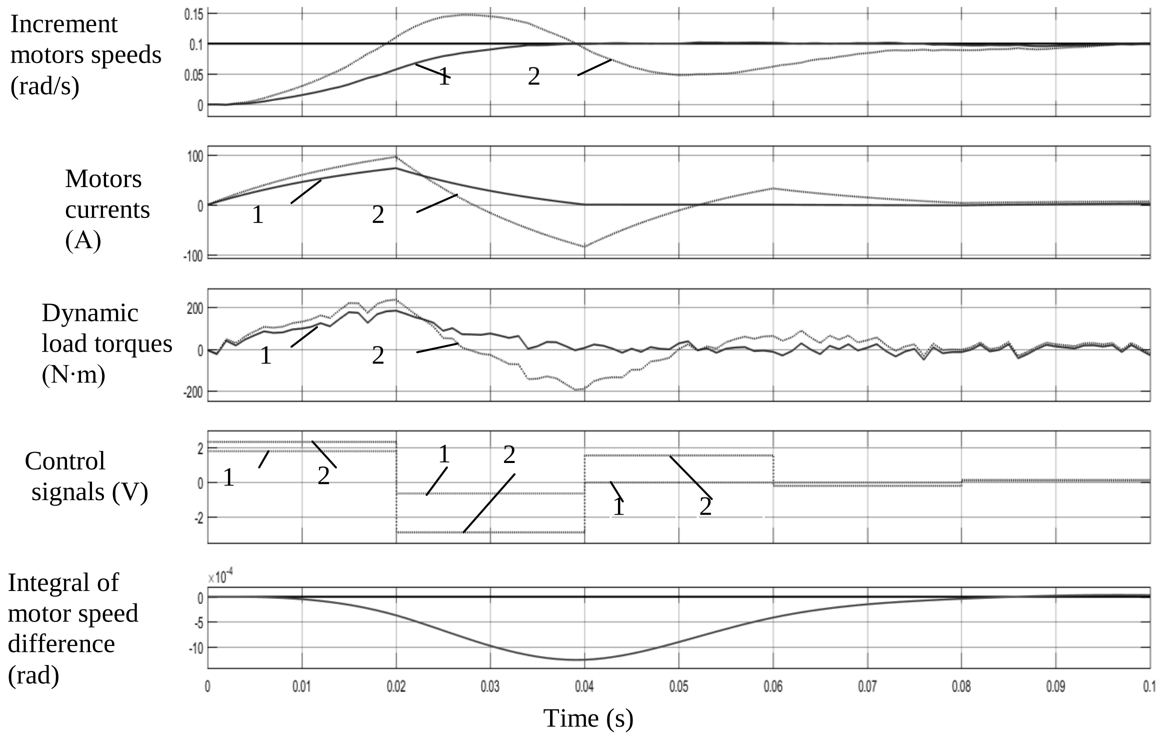

Figure 2. The reaction of EMCS to change the speed setting.

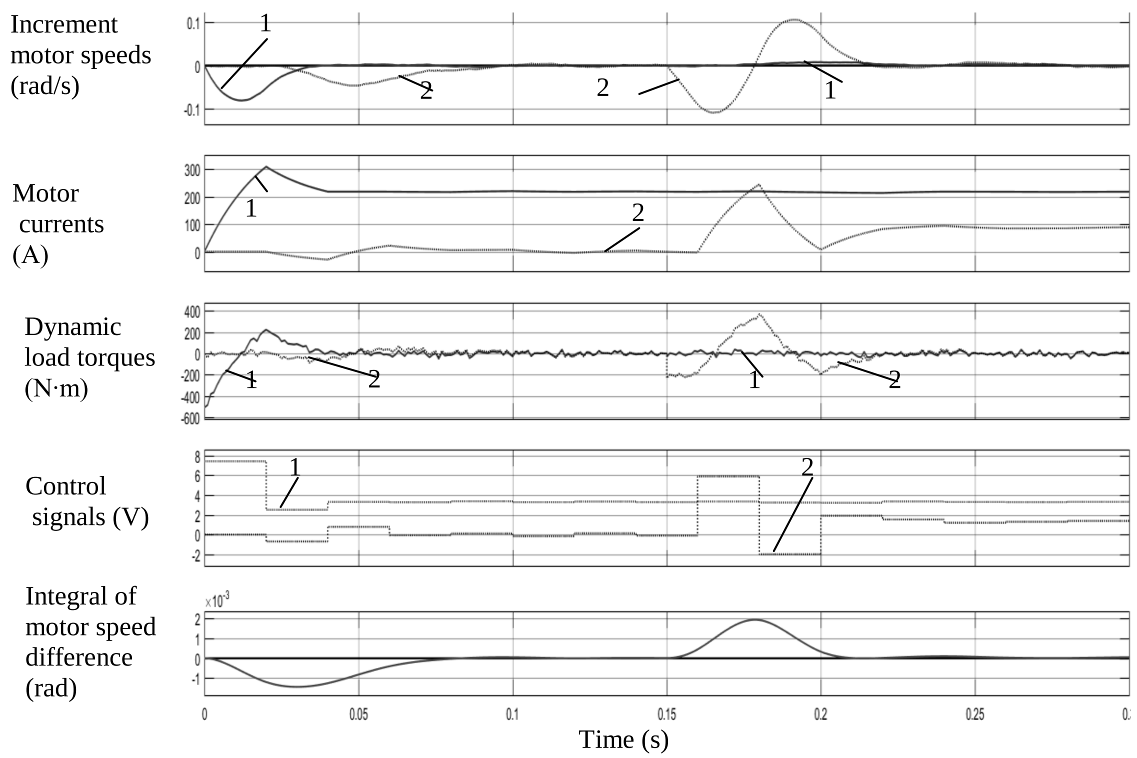

Figure 3. The reaction of EMCS to change drive loads.

3. Results

The paper considers an approach to solving the problem of reducing the mutual influence of electric drives on the stabilization of machine wire speeds and maintaining their predetermined ratio in conditions of obviously unpredictable changes in loads on their shafts, which should lead to an increase in the quality of paper (cardboard) produced on the twin-fourdrinier PMM. It is proposed for the synthesis of the EMCS one of the drives to be seen as an autonomous system of speed stabilization, and the other to synthesize on the principle of tracking control with integral control of the difference of the wires velocities. To improve the speed and accuracy of stabilization of wire velocities, it is proposed to apply finite control of electric drives, which provides theoretically a finite time for establishing transients. For the fifth-order EMSU model and the control period of 0.02 s, the time of finite control does not exceed 0.1 s, while the EMCS demonstrates the properties of astatic control, which allows reducing the speed deviations from the set values in steady-state modes to zero. Note that the steady-state value of the integral of the difference in wire velocities also tends to zero, which indicates almost zero displacement of the paper layers formed by both grids.

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References

[1] Ivanov S N 2007 *Paper Technology* (Moscow: Forest industry) p 696.

[2] Kurov V S and Kokushin N N 2008 *Paper and cardboard machines* (St. Petersburg: Polytechnic University) p 585

[3] Shestakov V M 1989 *Papermaking electric drive systems* (Moscow: Forest industry) p 240.

[4] Didenko E E and Meshcheryakov V N 2016 Control of the electric drive of looper at the strip entrance to the gap between two stand of finishing group of the hot rolling mill *Electrical and data processing facilities and systems* vol 12 pp 26-31

[5] Kharchenko A P, Slepokurov Yu S and Karevskaya Yu N 2018 Study of tracking systems in Matlab when exposed to disturbances in the control circuit *Bulletin of the Voronezh state technical university* vol 14 pp 41-45

[6] Bortsov Yu A, Polyakhov N D and Putov V V 1984 *Electromechanical systems with adaptive and modal control* (St. Petersburg: Energoatomizdat) p 216

[7] Kuo B 1986 *Theory and design of digital control systems* (Moscow: Mechanical Engineering) p 448

[8] Gayduk A R, Belyaev V E and Pyavchenko T A 2011 *Theory of automatic control in the examples and problems solutions in MATLAB* (Moscow: Lan) p 464

[9] Dorf R C and Bishop R H 2002 *Modern control systems* (Moscow: Laboratory of basic knowledge) p 832

[10] Kazantsev V P and Dadenkov D A 2012 On the Synthesis of Discrete Continuous Control Systems with Elastic Dissipative Links for Electric Drives *Russian Electrical Engineering* vol 83 pp 605-608

[11] Aleksandrov V M 2009 Sequential synthesis of time optimal control by a linear system with disturbance Siberian Electronic Mathematical Reports vol 6 pp 385-439

[12] Lyakhomskii A, Perfilieva E, Petrochenkov A and Bochkarev S 2015 Conceptual design and engineering strategies to increase energy efficiency at enterprises: Research, technologies and personnel *Proceedings of 2015 IV Forum Strategic Partnership of Universities and Enterprises of Hi-Tech Branches (Science. Education. Innovations)* pp 44-47